# 2.0 GROUNDWATER RESOURCES AND GEOLOGY

## 2.1 Introduction

As a component of the Phase 2 Technical Assessment for the Sol Duc-Hoh Watershed (WRIA 20), Golder conducted an assessment of the groundwater resources in the WRIA. The primary objective of the assessment is to characterize the role of groundwater in each sub-basin by examining existing reports, geological maps, well logs, and other information.

### 2.1.1 Study Area

WRIA 20 comprises approximately 1,190 square miles of the western Olympic Peninsula in Washington State. The watershed is characterized by rugged and varied topography with lowland valleys containing coniferous rainforests, and craggy mountains containing alpine meadows and glaciers in the interior. Topographic elevation in WRIA 20 ranges from 7,965 feet on the summit of Mt. Olympus in the east to sea level at the Pacific Ocean in the west. WRIA 20 exhibits some of highest total annual rainfall in the United States, with an average annual rainfall total of greater than 240 inches in the vicinity of Mt. Olympus. Major rivers in WRIA 20 include the Sooes, Ozette, Dickey, Sol Duc, Quillayute, Calawah, Bogachiel, and Hoh Rivers.

### 2.1.2 WRIA 20 Geologic History

The geology of the Olympic Peninsula is unique and interesting. The peninsula contains a thick sequence of Tertiary submarine basalt (Crescent Formation - erupted 60 to 50 million years ago [mya]) that has been thrust over younger Tertiary marine sedimentary rocks (sandstones, siltstones, and shales deposited between approximately 50 and 24 mya). The sediments comprising the marine rocks were originally deposited in an oceanic trench created by the west-to-east subduction of oceanic crust. When the wedge of sediments reached a critical thickness, subduction could longer continue and the wedge began to push up the overriding coastal slab of oceanic crust that it was formerly subducting beneath. Tectonic uplift of the Olympic Mountains associated with overthrusting of the basalt began approximately 17 mya. Today, the Crescent Basalt can be observed forming a "crescent" shape, open to the west, of steeply dipping rocks that enclose the interior Olympic Mountains, which themselves are comprised of highly deformed marine sedimentary rocks.

As the uplift of the Olympic Mountains continued, streams became incised, creating an erosional landscape of steep, rugged valleys. During the Pleistocene epoch (beginning approximately two million years ago), global climate patterns shifted and a series of alternating cool and warm periods began, which resulted in glacial and interglacial episodes. The glacial intervals allowed ice from British Columbia to flow southward into Washington numerous times during the Pleistocene. The most recent glaciation in Washington is referred to as the Vashon Stade, which reached maximum advancement approximately 13,000 to 12,000 years ago. As the Cordilleran ice advanced into western Washington, it split into two lobes, with one lobe filling the Straight of Juan de Fuca and the other advancing southward into Puget Sound lowland.

As Cordilleran glaciation progressed, alpine glaciers in the interior mountains of the peninsula also grew, and advanced into the valleys previously formed by incised streams. The alpine glaciers, though much smaller than the Cordilleran glaciers, deeply eroded the landscape creating the rugged topography that characterizes the Olympic Mountains today. Remnants of the larger alpine glaciers remain in the peaks of the Olympic Mountains. Meltwater streams draining the alpine glaciers deposited sand and gravel that comprise the most important hydrogeologic units in WRIA 20. Glacial sediments form the primary aquifers from which groundwater is withdrawn today for drinking and other uses.

Glacial sediments also play a role in the surface water in WRIA 20. In addition to the valley sediments which contain most of the WRIA's major rivers, glacial sediments serve to impound several lakes. Ozette Lake is dammed by a glacial moraine, which forms a ridge on the west side of the lake. Dickey Lake and Lake Pleasant are both surrounded by glacial sediments. Crescent Lake (outside of WRIA 20) is dammed on its eastern side by landslide debris associated with the recession of the glaciers.

### 2.1.3 Previous Studies and Data Sources

There are few published reports describing the hydrogeology of WRIA 20. Those identified by Golder include:

- Two reports regarding the hydrogeology in the vicinity of the Hoh Indian Reservation (Luxton, 1995 and Lum and Nelson, 1986); and
- A report on the water resources of the Makah Indian Reservation (Dion, Walters, and Nelson, 1980).

Geologic map coverage and structural information are included in:

- Rau (1973 and 1979);
- Long (1975 and 1976);
- Tabor and Cady (1978a and 1978b);
- Thackray (1997);
- Gerstel (1999); and
- Washington State Department of Natural Resources (WDNR, 2001) - 1:100,000 scale digital coverage.

Because very few detailed data exist about the hydrogeology in WRIA 20, large-scale surficial geologic map coverage of WRIA 20 was examined in order to determine important hydrogeologic units. Using the WDNR digital 1:100,000 geologic coverage (WDNR, 2001), a geologic map was produced by consolidating the existing coverage into several groups which focused on outcrops of sedimentary rocks, basalt bedrock, and the distribution of glacial sediments in WRIA 20 (Figure 2-1). The consolidated geologic map provided a base on which to plot locations of well logs that describe subsurface conditions at a particular location (Figure 2-2). Plotting the surface and subsurface data together allows for a better understanding of the hydrogeologic conditions in WRIA 20.

Logs for water wells located within WRIA 20 (approximately 324 well logs) were downloaded from Ecology's online site (http://apps.ecy.wa.gov/welllog/textsearch.asp) and hardcopies of the well logs are stored in Golder's project files. A total of 295 (or approximately 91%) of the wells are located in Clallam County and 29 (or approximately 9%) of the wells are located in Jefferson County. The well logs on file at Ecology constitute a portion of the total number of wells actually drilled in WRIA 20. This discrepancy arises because submittal of well logs to Ecology was not required prior to 1971. Therefore, some wells drilled prior to 1971 likely do not have an associated well log available for review. It is unknown what the exact percentage of total wells the logs on file with Ecology represent, but it is likely that a majority of the wells in WRIA 20 have an associated log at Ecology.

A spreadsheet database was developed to catalog hydrogeologic information for selected wells located throughout WRIA 20 with the objective of providing spatial information on aquifer characteristics to use in conjunction with geologic maps. Information on location, geology and hydrogeology from 270 selected well logs was input into the database. This represents approximately

83% of all the water well logs in WRIA 20 currently on file with Ecology. Well logs were selected for inclusion in the Golder well log database using the following criteria:

- Adequate location description (Township, Range, Section [TRS]);
- Detailed geologic description (clear, plausible description of material encountered);
- Well testing information (test type, pumping rate, drawdown measurement, duration); and
- Sufficient completion information (screened interval, construction details, and/or abandonment details).

The following information was noted for each well log (where available):

- Well location (TRS ¼ ¼);
- Owner first/last name;
- Well county;
- Ground elevation (from well log or estimated from U.S. Geological Survey [USGS] 7.5-minute topographic quad);
- Water level depth below ground surface/water level elevation/date;
- Well diameter/Screen type;
- Surface seal depth;
- Top of screen below ground surface/top of screen elevation;
- Bottom screen below ground surface/bottom of screen elevation;
- Screen length/mid-screen elevation;
- Bottom of hole below ground surface/ bottom of hole elevation;
- Screened unit;
- Feet of material overlying screen;
- Depth to consolidated rock/type;
- Dry or abandoned wells; and
- Minimum thickness of screen unit.

Wells were not included in the Golder well log database if they did not have: sufficient geologic description, location information, or if one or more wells were already included from that ¼-¼ section. Figure 2-2 shows the location of all the well logs in WRIA 20.

### 2.1.4 Aquifer Parameters

Where well test information (i.e., pumping rate and drawdown) was available, the following hydraulic parameters were evaluated:

- **Specific Capacity (Cs)** is a measure of the performance of a well and is expressed as a flow rate per unit drawdown (gpm/ft). Specific capacity is a time dependant parameter until steady-state conditions are reached.

$$Cs = \frac{Q}{s}$$

Where:

Cs = Specific capacity (gpm/ft);

Q = pumping rate (gpm)

S = drawdown (ft)

- **Transmissivity** is a measure of the transmitting capacity of the aquifer and is expressed in units of $L^2/T$ (e.g., $ft^2$/day). It is also often expressed as a volume capacity (gallons per day) per unit thickness of aquifer (ft). Transmissivity for an aquifer can be estimated from the specific capacity using the following empirical formula (Driscoll, 1986):

$$T = \frac{Q * x}{s}$$

Where:

T = transmissivity of the well (gallons per day/foot)

Q = yield of the well (gallons per minute)

s = drawdown in the well (feet)

x = 2,000 (assumed value for a confined aquifer)

A well efficiency of 70% was assumed for each well based on professional experience. As a result of a number of factors (e.g. design, construction, development), wells are typically less than 100% efficient. The assumption regarding efficiency means that if a well exhibited a drawdown of 10 feet during a pumping test, it was assumed that inefficiency related to well construction resulted in some of the drawdown observed in the well, as opposed to being fully attributed to the aquifer properties. In this example (e.g. 10 feet of drawdown in the well with 70% efficiency), the aquifer immediately surrounding the well likely experienced only 7 feet of drawdown. This correction yields a higher specific capacity and subsequently a higher transmissivity than the raw drawdown data. An efficiency of 70% was applied to all wells in the database.

Approximately 43 water wells in WRIA 20 (approximately 13% of the wells with recorded logs) contained information indicating that they are “dry” (Figure 2-3), and it is assumed that very little or no water could be pumped from these wells. Of these, approximately 79% were located in shale, 19% were located in the unconsolidated sediments, and 2% were located in basalt. Driller's notes on the well logs indicate that in many instances, the casing was removed from the borehole and the well was abandoned with concrete. The locations of dry wells are very approximate because the logs for dry wells commonly did not include ¼,¼ section in their location description.

## 2.2 Groundwater Resources

### 2.2.1 Principal Hydrogeologic Units

Aquifers

The glacial sediments (along with the fluvial sediments associated with the rivers draining the upland areas) comprise the principal aquifers in WRIA 20 because of their abundance and relatively shallow water table where they are saturated. The aquifers in WRIA 20 are expected to be limited in extent and are probably laterally discontinuous over large areas as a result of the topography and original glaciofluvial depositional environments.

Wells logs on file at Ecology were examined to gather information about the hydrogeology of WRIA 20 (see Section 1.1.3 for discussion). Using the information gathered from well logs, the productive hydrologic units of the WRIA were classified as follows:

**Unlithified Sediments**

Glacially deposited materials (drift [coarse-grained only], outwash)
Non-glacial deposits (alluvial and fluvial sediments)
-*Coarse-grained (sand, gravel, sand and gravel, with trace silt/clay)*

The most significant sediment type for water production in WRIA 20 is sand and gravel deposited on top of the consolidated marine sediments and basalt. Sand and gravel can be deposited by present day streams or by meltwater streams draining from glaciers. The most productive glacially derived deposits are advance outwash sand and gravel, which were deposited as the glacier advanced. Drift is an ambiguous term and can include both till and outwash. Till is a highly heterogeneous, often compacted mixture of clay, silt, sand, and gravel that was deposited directly beneath the glacier and is not commonly expected to produce a significant amount of water.

Non-water producing units

Rocks that are unlikely to produce significant amounts of groundwater in WRIA 20 include:

**Unlithified Sediments**
Glacially deposited materials (drift [fine-grained only], till)
Non-glacial deposits (lacustrine sediments)
-*Fine grained (clay, silt, fine sand)*
**Marine Sedimentary Rocks**
-*Fine grained (shale, siltstone)*
-*Coarse grained (sandstone, conglomerate)*
**Igneous Bedrock**
-*Volcanic rocks (basalt and other shallow intrusive rocks associated with the Crescent Basalt - e.g. gabbro and diorite)*

In some cases, rocks such as sandstone and basalt can yield significant amounts of water if they contain interconnected fractures, but on the Olympic Peninsula, this does not appear to be the case, as several wells completed in these units were reported as being dry or produce very small amounts of water. The low permeability of the sedimentary rocks and basalt in WRIA 20 likely precludes large-scale production of water from these units.

Minor constituents that have an insignificant hydrogeologic role in WRIA 20 include other igneous rocks (tonalite, andesite, and dacite) and metamorphic rocks (schist, metavolcanics, metasedimentary and tectonic breccias).

### 2.2.2 Distribution of Wells in WRIA 20

There are seven sub-basins in WRIA 20 that have a number of water wells and five sub-basins with very few or no wells. These areas have informally been classified in Table 2-1.

Figure 2-2 shows the location of these sub-basins and their proximity to major rivers in the WRIA.

### 2.2.3 Hydrogeologic Characteristics of Geologic Materials

The transmissivity values for the wells included in the database are shown on Figure 2-4 and summarized in Table 2-2.

The average values shown for transmissivity are geometric means. Geometric means were used because transmissivity values occur over a large range and typically have a log-normal distribution. Approximately 63% of the wells contained in the database are completed in the coarse, unconsolidated sediments (sand and gravel). This distribution indicates that much of the groundwater development that has occurred in the WRIA in the glacial and non-glacial sediments is located in valleys, usually in close proximity to a river (Figure 2-2).

Total thickness of the unconsolidated units is generally less than 100 feet, but may be up to several hundred feet thick in some places in WRIA 20. It is important to note that within the total thickness of unconsolidated sediments, there are likely zones of water that are capable of storing water (in pore spaces of sand and gravel) and transmitting the water to wells during pumping. The sediments above and below these zones may contain water, but may not be permeable enough to allow movement of the water on short time scales (e.g. minutes, hours). The length of screen used in a well can be indicative of the thickness of the water producing layers encountered during drilling. The productive layers of sand and gravel within the total thickness of unconsolidated sediments are typically thin, with the Golder well log database indicating that the median thickness of screened units listed on well logs was 9 feet.

Additionally, the Golder well log database shows that the median thickness of coarse unconsolidated sediments of material overlying the water-bearing unit was 45 feet. The thickness of the overlying sediments ranged from 5 to 369 feet. Because the wells in WRIA 20 are generally shallow and most are located in river valleys, the interaction between groundwater and surface water may be very important to management of water resources. Groundwater-surface water interaction will be discussed in Section 1.3 of this report.

In general, the unconsolidated sediments are present above sea level, but in 12 wells in the database, the interface between the bottom of the unconsolidated sediments and the top of the consolidated rocks is below sea level. With the exception of one well (well 267 in Golder database), all of the wells are located more than a mile from the Pacific Ocean. Well 267 (owned by the U.S. Department of the Interior) is located approximately 1/3-mile from the Pacific Ocean. Pumping of water from unconsolidated sediments from below sea level close to (e.g. less than 0.5 mile) the marine shore may cause saline intrusion. This usually results in long-term degradation of water quality in the affected portion of the aquifer. Water quality impairment from saline water WRIA 20 has historically been a result of completing wells in a freshwater-salt water zone of diffusion and not a result of groundwater pumping (Drost, 1986).

Thickness of the unconsolidated sediments in WRIA 20 was determined from approximately 93 well logs that recorded occurrence of underlying consolidated rocks (Figure 2-5). In wells where consolidated rocks were encountered, the median depth to the consolidated rock was 48 feet. The thickness of unconsolidated sediments ranged from 18 to 295 feet. The wells which encountered consolidated rocks are generally located:

- Along the length of the Sol Duc and Quillayute Rivers (various townships);
- On the Makah Indian Reservation (Townships 32N and 33N, R15W); and
- Along the Calawah River near its confluence with the Sol Duc River (T28N, R14W).

Some wells encountered consolidated rock in the vicinity of the Hoh River in T26N, R13W and north of Lake Ozette (T30N, R15W and T31N, Ranges 14W and 15W).

2.2.4 Regional Groundwater Quality Concerns

There are no published reports detailing the groundwater quality of WRIA 20. A query of the State of Washington Department of Health (WDOH) database for water quality reporting between 1970 and 2002 (WDOH, 2002) is summarized below:

- No synthetic organic compounds (SOCs) or volatile organic compounds (VOCs) were detected, with the exception of some chlorination by-products that are typically associated with disinfection of water for drinking. One detect of o-xylene (a common component in gasoline and paint thinners) was detected below its maximum contaminant level (MCL); and,

- All inorganic parameters were less than drinking water standards with the exception of iron, manganese and lead in some wells. These exceedances are included in Table 2-3. Exceedances occurred for iron, lead, and manganese in 25%, 9%, and 14% of the reported results for each parameter, respectively. The source of lead in drinking water is typically from solder used in plumbing systems and rarely occurs in detectable concentrations in naturally occurring groundwater or surface water.

It is important to note that occurrences of lead (particularly at concentrations exceeding the action level) can be caused by the plumbing of the distribution system rather than by the source water. However, groundwater sources can also contain lead. Additionally, the reported exceedance level for lead of 0.0015 mg/L is not a maximum contaminant level (MCL), but rather an action level that requires a Treatment Technique if more than 10% of tap water samples exceed this concentration.

Water quality from wells drilled for the Hoh Indian Tribe in T26N, R13W, Sections 20, 28, and 29 (Luxton, 1995) is summarized in Table 2-4. All of the parameters indicated on Table 2-4 have secondary drinking water standards, which are primarily associated with aesthetic concerns (e.g., taste, color, etc.) and are not health concerns. The iron level of 0.3 mg/L is equal to the secondary

MCL. The pH values reported in Luxton (1995) range from 5.5 to 6. While low pH itself is not a health risk, water with a low pH (acidic) can be corrosive to pipes and if untreated can result in increased metal content (for example, copper, lead, zinc and cadmium).

Although the extent of sea water intrusion in the coastal portions of WRIA 20 is unknown, limited data indicate that some wells in the WRIA are impaired by marine water. This is shown mainly by elevated chloride concentrations and specific conductivity values. Water quality from wells drilled for the Makah Indian Tribe in T33N, R15W Section 5 and T32N, R15W Sections 10, 14, and 16 (Dion, Walters, and Nelson, 1980) is summarized in Table 2-5.

Water quality from wells drilled for the Quileute Indian Tribe in T25N, R15W Sections 23 and 25 (Luxton and Bliemeister, 1989) are summarized in Table 2-6. Most of the parameters indicated on Table 2-6 have secondary drinking water standards, which are primarily associated with aesthetic concerns (e.g., taste, color, etc.) and are not health concerns. Nitrate is associated with a primary drinking water standard (10 mg/L), but measured concentrations were far below the standard. The iron level ranged from 0.03 to 0.7 mg/L. The secondary MCL for iron is 0.3 mg/L, indicating wells serving the Quileute Indian Reservation may have water quality problems associated with elevated iron concentrations (e.g. fixture staining, well encrustation, staining of clothes during laundering).

Dion, Walters, and Nelson (1980) note that the observed water quality impairment may be the result of the wells tapping brackish water that was trapped in aquifer materials when they were originally deposited (in a marine environment) rather than the result of sea water intrusion. However, the potential for sea water intrusion exists in WRIA 20 if groundwater development is focused in a coastal aquifer at or below sea level.

Both Jefferson and Clallam counties monitor critical aquifer recharge areas (CARAs). Jefferson County manages CARAs under JCC 18.15.240, which can be found online at http://search.mrsc.org/nxt/gateway.dll/jfsnmc?f=templates&fn=jfsnpage.htm$vid=municodes:JeffersonCounty. Clallam County also manages CARAs under CCC 27.12.600, which can be found at http://search.mrsc.org/nxt/gateway.dll?f=templates&fn=cllmpage.htm$vid=municodes:Clallam.

## 2.3 Groundwater-Surface Water Interaction

### 2.3.1 Hydraulic Continuity

Hydraulic continuity is the degree to which groundwater is connected to a nearby surface water body. Pumping in a well can induce recharge from the surface water body (e.g. river or lake). Rivers may lose water to groundwater, or groundwater may seep to streams and increase their flow. The dominant condition in terrains similar to that of WRIA 20 is that streams gain from groundwater seeps, although short reaches of the stream may be losing.

The nature of the connection between rivers and shallow sediments in WRIA 20 is largely unquantified. There are no published studies that have focused specifically on the relationship between surface water and groundwater in WRIA 20. The Water Quality and Habitat Level 1 Assessment (Hook, 2004) mentions that there is a noticeable groundwater contribution in certain reaches of the Hoh and North Fork Calawah Rivers. In both cases, groundwater discharge to the rivers is evidenced by temperature variations along the channel. Data included with the East-West Dickey Creek Watershed Analysis indicate that there are fluctuations in stream temperature along the creek branches that may be related to groundwater discharge (Rayonier, 1998). The Washington State Department of Natural Resources (WDNR) North Fork Calawah Watershed Assessment

Module C Hydrologic Change Assessment (Jackson, 1997) notes that the river goes dry in the following locations:

- T29N, R12W Secs. 13, 14, 15, 24; and
- T29N, R11W Secs. 15, 16, 17, 18, 19, 20.

There are indications that seasonal water level fluctuations along the river channel can be considerable. According to Jackson (1997), the water table beneath certain reaches of the North Fork Calawah can be deeper than 40 feet beneath the river during some periods in the summer. The thickness of the unconsolidated sediments infilling the river valley in the drying reach of the North Fork Calawah ranges between 100 feet to over 350 feet, as extrapolated from the angle of valley walls at several locations (Jackson, 1997). If these thickness estimates are correct, there are sections of river valleys in WRIA 20 that are capable of transmitting large amounts of subsurface flow. There are no well logs located near the drying reach of the North Fork Calawah to independently verify the thickness estimates.

Lum and Nelson (1986) noted the presence of springs and spring-fed ponds near the Hoh Indian Reservation. Luxton (1995) noted springs outcropping along the northeast side of the Olympic National Park border that lies east of the Hoh Indian Reservation. In both cases, the springs are likely associated with the draining of upland areas and discharge of water to lower elevations near rivers. This configuration is likely common throughout the valleys of WRIA 20.

### 2.3.2 Regulatory Issues

There are 12 Group A systems in WRIA 20 with 20 wells, and 26 Group B systems with 26 wells listed in the WDOH database (Figure 2-6). Because of the configuration of the hydrogeologic units (i.e. unconsolidated sediments filling river valleys), a great deal of groundwater in WRIA 20 is likely to be hydraulically connected to surface water to some degree. As a well pumps, a cone of depression in the groundwater around the well will extend laterally into the surrounding aquifer. During the early part of the pumping, the water level in the pumping well will go down. However, when the cone of depression intersects a surface water body (e.g. a river channel), a hydraulic gradient develops between the groundwater in the aquifer and the water in the river. If the streambed is hydraulically connected with the aquifer, river water will percolate through the streambed material under the influence of the hydraulic gradient. Therefore, the river recharges the aquifer at an increasing rate, as the cone of depression around the pumping well grows larger. When the rate of recharge to the aquifer equals the rate of discharge from the well, the cone of depression and the water level in the pumping well become stable. This condition is commonly reflected as a horizontal line on a plot of water level drawdown versus time.

Public drinking water wells that have hydraulic connection with surface water bodies in Washington State are increasingly being regulated by WDOH. WDOH considers these wells as GUI (groundwater under the direct influence of surface water) and Federal Surface Water Treatment Rule requires that all Group A public water systems determined to be GUI treat their water. The GUI Program focuses specifically on drinking water sources that appear to be at risk of microbiological contamination associated with surface water. The program provides a means for identifying these types of sources (referred to as “potential GUI sources”), characterizing the degree of risk for microbiological contamination (through specific data collection requirements and methodologies), interpreting the results of the characterization, and determining appropriate follow-up contaminant risk mitigation actions.

The WDOH regional engineers for Clallam and Jefferson Counties were contacted in order to quantify the nature of groundwater-surface water interactions in public water system wells in WRIA 20. The engineers noted that there are no significant water quality issues in the WRIA. Additionally, no public drinking water sources have been identified as GUI, but several sites are being investigated for the possibility.

According to WDOH, water systems with GUI sources must achieve at least 99.9% removal or inactivation of *Giardia lamblia* cysts and at least 99.99% removal or inactivation of viruses. To accomplish this, systems must do all of the following:

- Filter water, unless certain source quality and site-specific conditions are met to avoid filtration;
- Disinfect water; and
- Be operated by qualified personnel.

Systems with GUI sources or sources identified by the department as being "potential" GUI sources have several compliance options to choose from, including:

- Modifying the groundwater source to eliminate direct surface water influence;
- Developing an alternate WDOH-approved source (for example, develop a protected groundwater source or purchase from a nearby approved public water system);
- Attempting to meet the source quality and site-specific criteria to remain unfiltered; and
- Installing filtration equipment.

## 2.4 Groundwater Availability - Summary and Recommendations

Groundwater development in WRIA 20 is limited by the productivity of aquifers. The locations of wells in WRIA 20 are concentrated mainly in river valleys. Most wells in the WRIA are shallow (i.e., median well depth in the Golder well log database was 62 feet) and are completed in unconsolidated sediments, which lie on top of low permeability consolidated rocks (marine sedimentary rocks and basalt). Where fully penetrated by boreholes, the unconsolidated deposits are generally less than 100 feet thick. The low transmissivity of the underlying consolidated rocks preclude their use as aquifers on a large scale in WRIA 20.

Despite having annual rainfall totals of over 240 inches in some areas of the WRIA, there are still many wells drilled that do not produce sufficient water for domestic use (approximately 13% of the well logs on file with Ecology indicated that the well did not produce sufficient water). Additionally, wells located near rivers may be hydraulically connected to the surface water which requires that in order for water resource management to be successful, development of groundwater must be directed in a manner that does not impair instream flows.

### 2.4.1 Quantifying Water Present

Because very little information is currently available to determine the amount of groundwater present in WRIA 20, the amount of water currently available and available for future appropriation cannot be accurately quantified at this time. Accurate quantification of the water present requires collecting and analyzing a significant amount of data about a selected area. Although WRIA 20 is large, groundwater development has historically occurred in focused areas; in particular, the lower reaches of the WRIA's major river valleys. Because groundwater development is geographically constrained, hydrogeological studies should focus on a particular area in order to characterize an aquifer and in turn, the amount of water present. Information helpful to characterize an aquifer and the water present includes:

- thickness and extent of aquifer;
- aquifer boundaries;
- aquifer recharge and discharge zones;
- annual well production records;
- aquifer parameters (storativity, transmissivity, response to pumping); and
- hydraulic head data (water level information with adequate spatial distribution and seasonal record).

Because the hydrogeologic conditions of the WRIA are likely to be highly variable not only between valleys but also along valleys, hydrogeologic studies specific to a particular area are recommended rather than a generalized study covering large areas.

#### 2.4.2 Quantifying Available Water

The amount of water stored in the aquifers can be determined only by compiling and analyzing the data described above. Additionally, identifying the degree of hydraulic continuity between surface water and groundwater will help determine how much water is available for use without impairing instream flows. Establishing minimum instream flows in creeks in the WRIA will also guide the determination of the amount of groundwater available for pumping.

#### 2.4.3 Quantifying Water Available For Future Allocation

Once the amount of available water has been determined, the amount available for future allocation should be estimated. This requires a detailed evaluation of how much water is currently being used and an estimate of additional future water demand (if any) in the WRIA. The Water Use technical assessment (Section 4) addresses current and future water use. The Planning Unit could choose to characterize available groundwater in areas of WRIA 20 that are likely to face future groundwater development pressures. Using the estimated locations of future development, information could be extracted from the Golder well log database regarding aquifer characteristics found in these regions (e.g., transmissivity, depth of unconsolidated sediments, estimated depth of productive zones, location of dry wells).

#### 2.4.4 Other Recommendations

The supply of shallow groundwater is susceptible for a number of reasons: seasonal fluctuations in water level, contamination from surface sources, and potential GUI. In order to protect the water supply, shallow groundwater requires careful management. Several options to protect and develop shallow groundwater that can be incorporated into Watershed Planning are summarized below. There is no fixed depth that defines a shallow well and wells at any depth may be susceptible to certain impairments such as contamination and declining water levels. The term shallow, as it is used here can be thought of as wells less than about 150 feet deep.

Groundwater/Surface Water Interaction

Because of the proximity of wells to rivers in WRIA 20, there is a need to understand the degree of hydraulic continuity between groundwater and surface water. In the absence of any published data, some options for increasing the understanding of groundwater/surface water interactions include:

- Compiling anecdotal evidence (e.g., location of springs and seasonally dry reaches of dry river beds);
- Developing a stream gaging program (long term - continuous) or study of instream flows (short term – seasonal) to identify gaining/losing reaches (a.k.a. seepage reaches) of streams on selected rivers;
- Performing pumping tests on wells sited near rivers (e.g. distance from river dependent upon local conditions) and measuring streamflow and water quality (e.g. temperature, conductivity, microscopic particulate analysis); and,
- Intensive streambed studies (similar to USGS in Lower Dungeness River; Simonds and Sinclair, 2002).

These options range in cost and level of technical effort required and could conceivably be accomplished as supplemental assessments as part of the watershed planning process.

Wellhead Protection

The Planning Unit may decide to develop a program to assist public water systems in developing wellhead protection plans. Group A wells located near surface water bodies must comply with guidelines set forth by WDOH and wellhead protection plans can help identify and protect aquifer recharge areas for water supply wells in the WRIA. A program of developing uniform wellhead protection plans in the WRIA will help smaller system wells share a similar degree of water quality protection as larger systems. According to the WDOH database, there are currently 12 Group A systems in WRIA 20 with 20 wells (and 26 Group B systems with 26 wells). The first step to developing a wellhead protection plan program may be to survey the public water systems and compile the results to rank the systems and determine where the most effort is needed to update the wellhead protection plans.

Informed Groundwater Development

Because of the cost associated with drilling a dry well, particularly to a private homeowner, future groundwater development in WRIA 20 should utilize techniques that give insight into the hydrogeologic conditions expected at a site before drilling begins. Examining well logs and extracting information from the Golder well log database is one method to increase the understanding of the hydrogeology of an area. Another means to identify favorable hydrogeologic conditions for siting a well are geophysical techniques (e.g. electrical resistivity, ground penetrating radar, and seismic refraction) that provide information on subsurface materials of an area without installing a well. Depending upon the parameters measured and the size if the area investigated, a geophysical study may be comparable in cost to installing a well at a site where subsurface conditions are unknown.

<u>Aquifer Storage and Recovery</u>

Aquifer storage and recovery (ASR) entails the use of wells to recharge treated water directly to an aquifer unit, for recovery at a later time. Implementing a successful ASR program entails considerable knowledge of the hydrogeologic conditions of an area. The type of aquifer information required is similar to that obtained from in-depth hydrogeologic studies (Section 1.4.1) and also includes: porosity, specific yield, storage coefficient data, as well as aquifer pressure conditions/response to changes. In order for ASR to be successful, aquifer materials must have sufficient storage and have boundaries which inhibit the movement of water. Because of the limited thickness of most of the aquifer zones in WRIA 20 and the proximity to surface water bodies, identifying a site suitable for ASR is likely to require a site-specific hydrogeologic investigation complete with pumping test(s) and perhaps computer modeling. Future hydrogeologic investigations may identify areas in the WRIA where ASR programs should be explored in greater detail. Guidelines for planning and designing typical ASR projects can be found in the Standard Guidelines for Artificial Recharge of Ground Water (ASCE, 2001)

Infiltration to aquifer units exposed at the surface entails impounding and spreading water over a wetted area for recharge. Surface infiltration may be successful in areas of WRIA 20 where water (e.g. stormwater runoff) can be captured and directed to areas where groundwater flow paths allow for a delayed release back to surface water bodies. Recharge to shallow aquifer units may not provide long-term storage of water (e.g. months) but instead may allow groundwater production to be more sustainabe by augmenting stream baseflow.